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BELLCOMM, INC.

SUBJECT: Communications for Long Duration Earth Orbital Missions Case 228

DATE: July 7, 1967

FROM: R. K. Chen

ABSTRACT

The communication capacity and the communication system requirements between a manned spacecraft in Earth orbit and the Mission Control Center (MCC-H) for the 1972-1975 period is discussed in this memorandum. The discussion includes the utilization of the present Manned Spaceflight Network (MSFN) and a projected communication satellite network, known as the Data Relay Satellite System (DRSS), for transferring wideband information.

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MEMORANDUM FOR FILE

I. Introduction

This memorandum provides a gross estimate of the communication capacity and the communication system requirements between a manned spacecraft in low Earth orbit and the MSFN for the 1972-1975 period. The missions considered would be of extended duration where a large amount of scientific data will be collected. It is likely that, for such a mission, the amount of data collected would exceed the data transmission capability of the communications system. Therefore, it becomes necessary to seek a balance amongst data collection, storage, and transmission planning. In this memorandum, discussions are presented on the probable upper bound of data transmission capability of the communications system involved, based on two possible MSFN configurations. The first is to maintain the present MSFN with some improvements, and the second would involve the augmentation of the Data Relay Satellite System (DRSS)* to the network.

II. Assumptions

It is assumed that the long duration manned spacecraft will be in a 200 nm circular orbit with inclinations of either 23° or 45°. The spacecraft would be configured as an orbital workshop and therefore it would have more advanced communication subsystems than the present Apollo CSM configuration. The major improvements, which may be realized, for the spacecraft are larger antenna, better receiver noise figure by using uncooled parametric amplifiers (160°K noise temperature) and higher power transmitters.

Two MSFN configurations are assumed; they are:

1. The present Apollo USB ground network plus two ships. The ground stations are: MILA, Grand Bahama, Bermuda Ascension, Grand Canary, Madrid, Carnarvon, Canberra, Guam, Hawaii, Goldstone, Guayamas, Antigua, and Texas. For the sake of simplicity and other limitations

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*Two Phase A DRSS studies were completed by contractors for OTDA.

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discussed later, all stations are assumed to be of equal capability based on a station equipped with a 30 foot diameter antenna.

2. A MSFN based on the augmentation of the DRSS which consists of three geostationary satellites and two ground stations. One ground station would be situated in the vicinity of MCC-H, and the other ground station situated near Canberra, Australia, serving as a relay terminal between satellites, as one of the satellites would not be visible to the continental United States. The DRSS satellites would use a retrodirective array type antenna for the communication link between the manned spacecraft and the satellites at S-band frequencies. A reasonable assumption for the array antenna gain would be 38 dB. A conventional 2 foot parabolic dish antenna is assumed for the communication link between the satellite and the ground terminal at X-band frequencies (7-8 GHz). Six dB noise figure receivers are assumed for the DRSS which implies solid state preamplifiers.

A summary of the system parameters are presented in Table I.

Assumptions are also made on the maximum practicable data transmission capabilities. The limitations are made for single carrier frequency dictated by circuit and component design limits. It is assumed that the maximum realizable RF bandwidth would be 10 percent. In the case of S-band frequency carriers, the bandwidth would be approximately $\pm$ 100 MHz. However, for a digital system it is further assumed that the maximum bit rate that can be generated in a spececraft would be 20 megabits per second. It is also anticipated that a considerable problem may exist in frequency spectrum assignment; for instance, the S-band down link frequency spectrum allowed for NASA use is only 30 MHz (2270 MHz - 2300 MHz) and the total S-band down link spectrum allowed, including the DOD Space Ground Link Subsystem (SGLS) is 100 MHz (2200 MHz - 2300 MHz). The frequency allocation problem is an area of study by itself which has other than technical factors involved; especially, in the area of the philosophy for space-to-space frequency assignment. The spectrum allocation problem will not be included in this study as a basic system limitation.

III. Transmission Performance Calculations

The one way transmission equation,

$$SNR = \frac{ERP \times G_r}{K\ T_{eff}\ B\ L_{fs}\ L_{syst}},$$

where: SNR = signal to noise ratio required

ERP = effective radiated power (product of transmitter power and antenna gain)

G_r = receiving antenna gain

K = Boltzman's constant

T_{eff} = effective noise temperature of receiving system

B = bandwidth

L_{fs} = free space path loss

L_{syst} = miscelleaneous system losses, is used for the transmission performance calculations. The calculations made are for wide band data only; the communication functions, such as voice, up-data, and tracking are not treated in this study. The implication is that the wide band data considered would dominate the communication system requirements, and the addition of the other functions can be provided with minor additions to the system. The modulation techniques used for the calculations are coherent PCM/PM for digital data transmission and FM for television transmission. A 6 dB performance margin is added to all calculations which accounts for design margin and transmission degradation from unfavorable weather conditions.

In the following, the communication system capabilities are calculated for the two possible MSFN configurations.

A. Present MSFN - Spacecraft

Calculations are made for 1) the transmission of 20 megabits/sec digital data and 2) 33 MHz analog data in 200 MHz rf bandwidth. These calculations are presented in Table II for the spacecraft to MSFN link. Table III presents a calculation of the required spacecraft antenna size, when transmitting commercial television from MSFN to the manned spacecraft. For all cases, it is seen that satisfactory performances can be obtained by using a 20 watt transmitter on the spacecraft with an 8 dB gain antenna. If the analog transmission from spacecraft to MSFN were restricted to commercial type television (4 MHz baseband bandwidth) all requirements can be met with an omni type antenna on the manned spacecraft.

B. Spacecraft-DRSS-MCC-H

A quick calculation would show that for this MSFN configuration the limiting links are those between the manned spacecraft and the DRSS satellites. Therefore all the calculations would be made for those links. It is also assumed that the satellite-Earth link would be made 10 dB better in SNR performance; therefore, the added thermal noise of that link would only degrade the satellite - manned spacecraft link by approximately 0.5 dB.

The effective radiated power required for the manned spacecraft to DRSS transmission link when transmitting 20 megabits per second digital data and 33 MHz of analog information is calculated in Table IV. The spacecraft receiver antenna gain for commercial type television transmission from DRSS to the manned spacecraft is calculated in Table V. It is seen that with a 15 ft diameter antenna (38 dB gain) on the manned spacecraft, approximately 40 watts of transmitter power is required to send 20 megabits per second digital data, and that 580 watts of transmitter power would be needed to send 33 MHz of analog information. Also with the 15 foot antenna, the manned spacecraft would be able to receive commercial quality television transmission. Again, if the analog data transmission from the spacecraft were restricted to television of the commercial quality (4 MHz baseband), then 70 watts of transmitter power would be sufficient.

A quick look was made on the possible advantage of using digital techniques for television transmission. A straight forward PCM technique, using a sampling rate twice the highest baseband frequency, and encoding each sample in six bits to provide 64 intensity levels, would require a transmission rate of 48 megabits per second. In order to confine the transmission to 20 megabits/sec, it is clear that some kind of data compression method is required. The particular method chosen is known as the Improved Gray Scale (ICS) system which is under development at RCA, Princeton.* A three to one bit reduction can be achieved with some sacrifice in the picture quality. The transmission calculation for digitized television is made in Table VI, the result indicates that a 3.3 dB advantage can be realized with the particular method used.

IV. Summary

From calculations provided in Section III, the communication capacity of the two MSFN configurations can be determined. For the case where DRSS is involved, the duty cycle of the MSFN is 100%, a total of 1.7×10^{12} bits/day of digital data can be obtained from the manned spacecraft. In order to transmit commercial type television from the spacecraft, slightly higher transmitter power would be required. In either case, a commercial type television can be received by the manned spacecraft. For the case of utilizing the present Apollo USB MSFN, the communication capacity is reduced by approximately a factor of 5, because of the coverage limitation. The spacecraft antenna gain and RF power requirements are summarized in Table VII for various cases considered in Section III.

Several major factors should be considered between the MSFN configurations as discussed below:

1. MSFN Complexity - It is clear that in the case of implementing the DRSS, an entirely new system is required. The parameters assumed for the DRSS satellite rely on the practicability of the retrodirective array antenna system which has not been used in any space application before. On the other hand, by utilizing the present MSFN, only slight ground station improvement would be required. But the larger problem is to transfer the data from the individual ground station to MCC-H. Conceivably, this can be done by the use of a commercial communication satellite system at a non-neglegible cost, unless real-time or near real-time data acquisition is not required at MCC-H.

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*W. T. Bisignani, et. al., "The Improved Gray Scale and the Coarse-Fine PCM Systems, Two New Digital TV Bandwidth Reduction Techniques", IEEE Proceedings, March, 1966.

2. Spacecraft Complexity - The use of DRSS type of MSFN configuration would require a large dish antenna on the spacecraft and higher power transmitters. On the other hand, an Apollo type transmitter and omni antenna is sufficient for communicating with the existing MSFN.

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Attachments
Tables I-VII

	Apollo USB MSFN	DRSS	Manned Spacecraft
Antenna Gain	44 dB (30 ft)	38 dB - Spacecraft Link 30 dB - Ground Link	To be determined
Receiving System Noise Temperature*	120°K	160°K	450°K to MSFN 225°K to DRSS
System Losses**	1.0 dB	4.5 dB	6 dB (transmit) 3 dB (receive)
Transmitter Power	10 kW	50 W to Spacecraft 20 W to Ground	To be determined

Table 1 Assumed System Parameters

* System noise temperature includes antenna temperature and receiver noise temperature.

** System Losses include antenna polarization loss, antenna pointing loss, diplexer loss, line loss, modulation loss, etc.

	Digital Transmission	Analog Transmission
Receiver Noise Spectral Density (120°K)	-207.8 dBW/Hz	-207.8 dBW/Hz
Bandwidth	73.0 dB (Bit rate BW)	83.0 dB (RF BW)
SNR Required	8.5 dB (10^{-4} BER)	10.0 dB*
Margin added	6.0 dB	6.0 dB
Received Power Required	-120.3 dBW	-108.8 dBW
Free space loss for 1200 nm slant range at 2.2 GHz	-166.0 dB	-166.0 dB
Receiving system loss	-1.0 dB	-1.0 dB
Transmitting System Loss	-6.0 dB	-6.0 dB
Receiving Antenna Gain	44.0 dB	44.0 dB
Net Loss	-129.0 dB	-129.0 dB
ERP Required (Spacecraft)	8.7 dBW	20.2 dBW

Table II <u>Manned Spacecraft to MSFN Transmission Calculation</u>

*Conventional FM, 200 MHz RF bandwidth can accommodate a baseband of 33 MHz by using a modulation index of 2 to yield a baseband SNR (Tone to Noise) of 25 dB,

Transmitter Power	40.0 dBW
Transmitting System Loss	-1.0 dBW
Transmitting Antenna Gain	44.0 dB
Free Space Loss	-166.0 dB
Receiving System Loss	-3.0 dB
Signal Power Received with 0 dB Gain Antenna	-86.0 dBW
Receiving System Noise Spectral Density (450°K)	-202.1 dBW/Hz
RF Bandwidth*	73.9 dB
SNR Required*	10.0 dB
Margin Added	6.0 dB
Receiving Signal Power Required	-112.3 dBW
Receiving Antenna Gain Required	-26.3 dB

Table III

Television Transmission From MSFN to Manned Spacecraft

* Conventional FM, using modulation index of 2,4 MHz television baseband bandwidth, baseband SNR = 34.5 dB (peak to peak to rms)

	Digital Transmission	Analog Transmission
Receiver Noise Spectral Density (1160°K)	-198.0 dBW/Hz	-198.0 dBW/Hz
Bandwidth	73.0 dB (Bit rate BW)	83.0 dB (RF BW)
SNR Required	8.5 dB (10^{-4} BER)	10.0 dB*
Margin for Relay Loss	0.5 dB	0.5 dB
Margin added	6.0 dB	6.0 dB
Received Power Required	-110.0 dBW	-98.5 dBW
Free Space Loss for 22,300 nm slant range at 2.2 GHz	-191.6 dB	-191.6 dB
Receiving System Loss	-4.5 dB	-4.5 dB
Transmitting System Loss	-6.0 dB	-6.0 dB
Receiving Antenna Gain	38.0 dB	38.0 dB
Net Loss	-164.1 dB	-164.1 dB
ERP Required (Spacecraft)	54.1 dBW	65.6 dBW

Table IV Manned Spacecraft to DRSS Transmission Calculation

* Conventional FM, using modulation index of 2 would yield a baseband SNR (tone to rms noise) of 25 dB, baseband bandwidth = 33 MHz approximately.

Transmitter Power	17.0 dBW
Transmitting System Loss	-4.5 dB
Transmitting Antenna Gain	38.0 dB
Free Space Loss	-191.6 dB
Receiving System Loss	-3.0 dB
Signal Power Received with 0 dB Gain Antenna	-144.1 dBW
Receiving System Noise Spectral Density (450°K)	-202.1 dBW/Hz
RF Bandwidths*	73.8 dB
SNR Required*	10.0 dB
Margin for Relay Loss	0.5 dB
Margin Added	6.0 dB
Receiving Signal Power Required	-111.8 dBW
Receiving Antenna Gain Required	32.3 dB

Table V

Television Transmission From DRSS to Manned Spacecraft

* Conventional FM, using modulation index of 2, 4 MHz baseband bandwidth, baseband SNR = 34.5 dB Peak to Peak to rms.

Transmitter Power	17 dBW
Transmitting System Loss	-4.5 dB
Transmitting Antenna Gain	38.0 dB
Free Space Loss	-191.6 dB
Receiving System Loss	-3.0 dB
Signal Power Received with 0 dB Gain Antenna	-144.1 dBW
Receiving System Noise Spectral Density (450°K)	-202.1 dBW/Hz
Bit Rate Bandwidth (16 MHz)	72.0 dB
SNR Required	8.5 dB
Margin for Relay Loss	0.5 dB
Margin added	6.0 dB
Receiving Signal Power Required	-115.1 dBW
Receiving Antenna Gain Required	29.0 dB

Table VI

Digitized Television Transmission from DRSS to Manned Spacecraft

	Spacecraft Antenna Gain	Spacecraft RF Power
S/C to MSFN*		
20 megabits/sec. Data	0 dB (Omni)	10 Watts
33 MHz Analog Data	8 dB	20 Watts
Commercial Quality TV	0 dB (Omni)	20 Watts
S/C to DRSS*		
20 megabits/sec. Data	38 dB (15 ft dish)	40 Watts
33 MHz Analog Data	38 dB	580 Watts
Commercial Quality TV	38 dB	70 Watts
Digitized IGS TV	38 dB	35 Watts

Table VII

Summary of Spacecraft Antenna and RF Power Requirements

In all cases, spacecraft is capable of receiving commercial quality television.

*5 times more data can be transfered using DRSS satellites than using present Apollo MSFN.